# Recent Activities of the Actinic Mask Inspection using the EUV microscope at Center for EUVL

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# Outline

1) EUV actinic mask inspection using EUV Microscope

2) EUV Microscope using a high-magnification objective with three multilayer mirrors

# EUV actinic mask inspection using EUV Microscope

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*Selete**
** Present affiliation: EIDEC*

# Outline

1) EUV microscope
2) Phase defect observation
3) Defect repairing using FIB and its observation
4) Conclusions

# Background

Total 11 sets of the commercial steppers for EUV Lithography will be delivered in 2013 ～ 2014.

Mask pattern defect ⇨ Electric circuit error ⇨ Device error

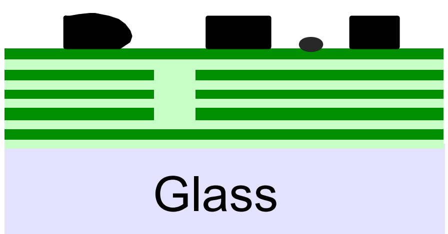
<u>EUV mask repair</u>
<u>and</u>
<u>the mask inspection for the repaired mask</u>
<u>is required</u>

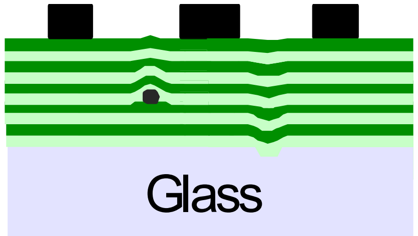
# Mask inspection method

Inspection by exposure wavelength

EUV Mask Defect

| Amplitude defect | Phase defect |
|---|---|




Affected with Intensity profile

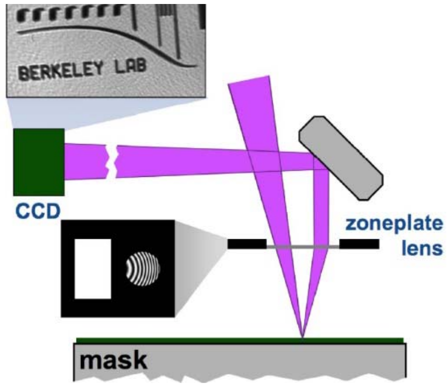
Affected with the phase profile (pit defect)

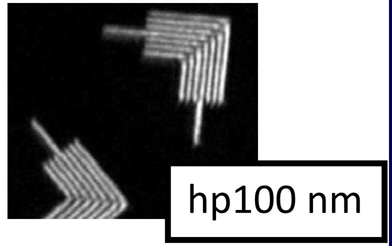
Pit and bump defects of 1-nm-depth are printable.

Difficult to inspect using DUV and SEM.

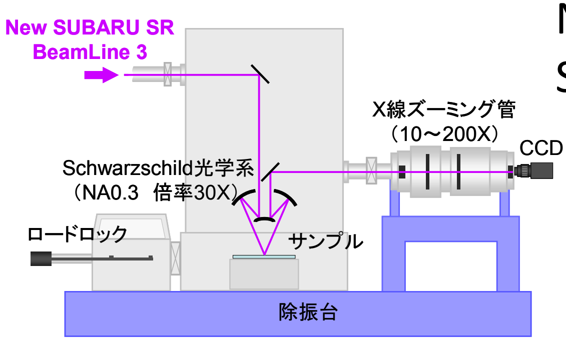
## EUV mask defect inspection tool

ALS
Zone Plate型

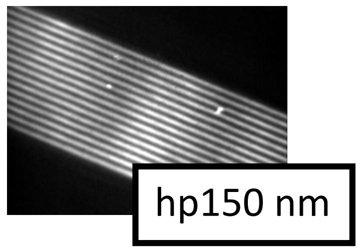


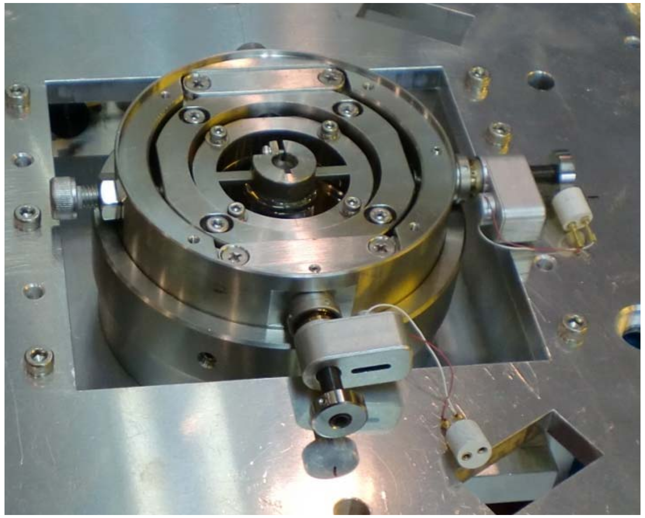

NewSUBARU
Schwarzschild型



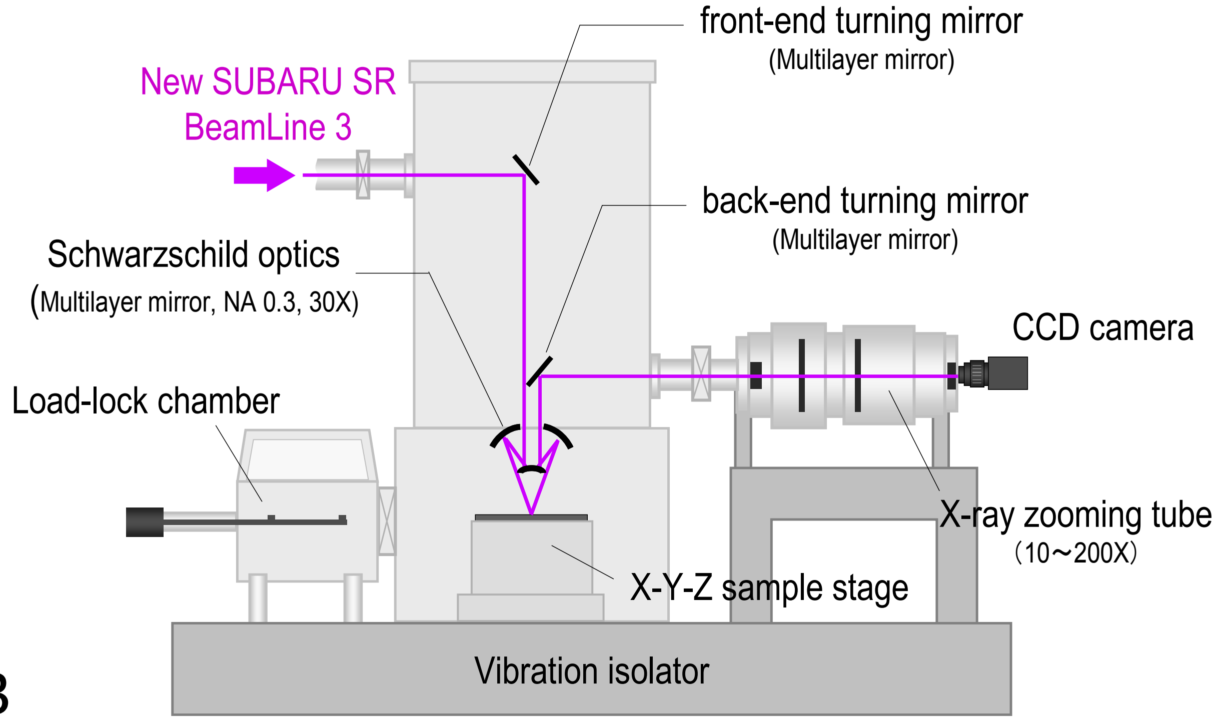

EUV顕微鏡



# Specification of EUV Microscope

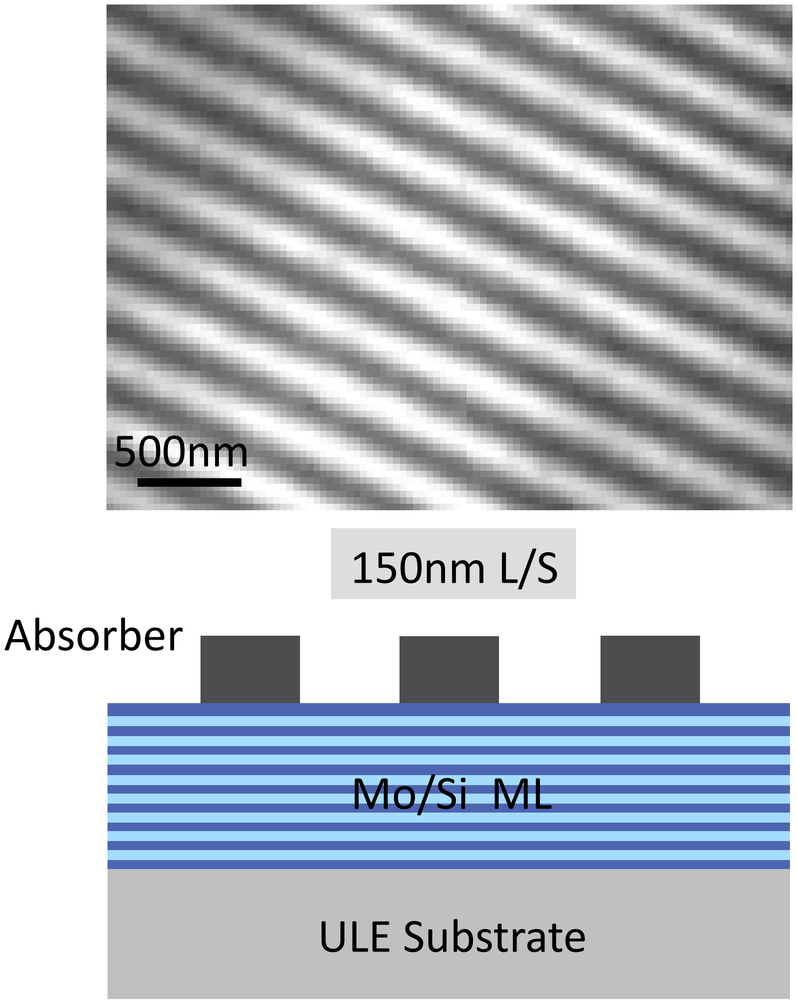


Schwarzschild optics
Magnification : 30X
Numerical aperture: 0.3

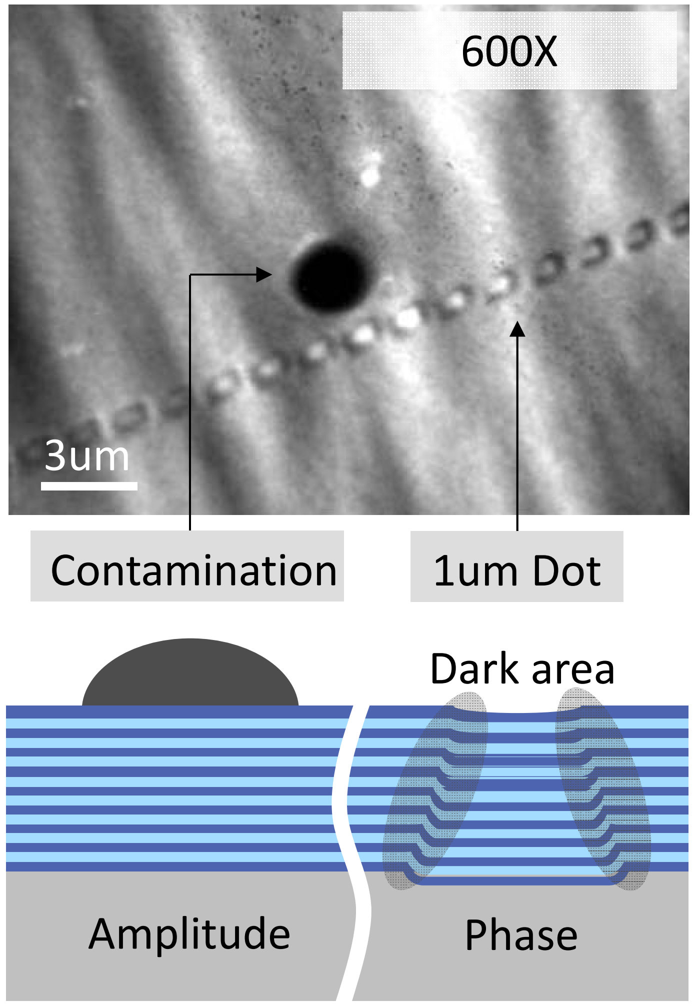



| | |
|---|---|
| ▪Light source | Bending magnet |
| ▪Total magnification | 300～6000x |
| ▪Resolution | 10 nm |
| ▪Method | Bright field |
| ▪Defect observation | Amplitude and phase defects |

# Mask defect inspection by EUVM

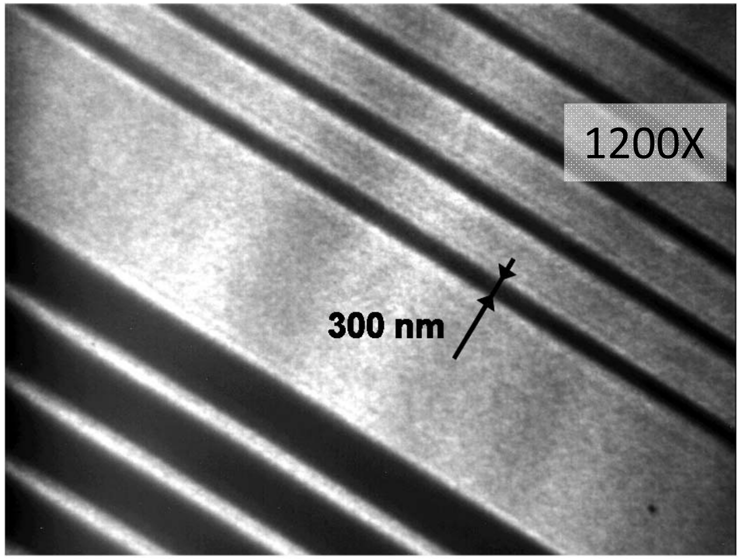



Finished mask

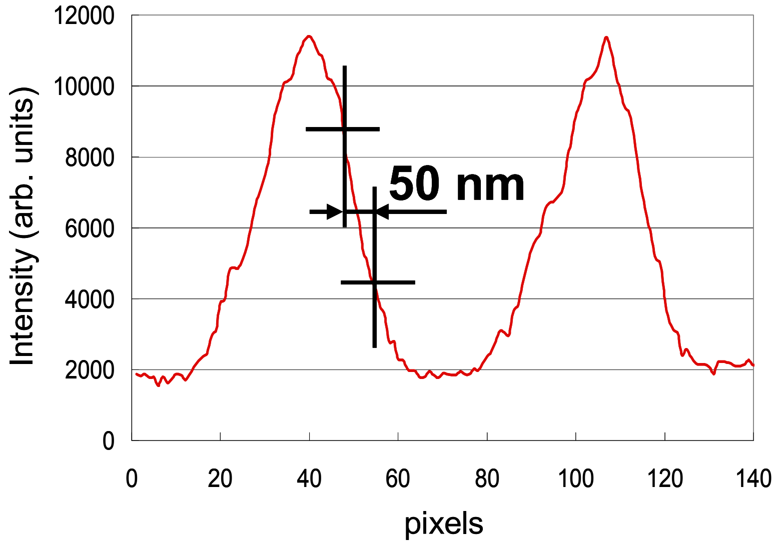



Blanks

# Resolution of mask defect by EUVM




Isolated line of 300 nm width

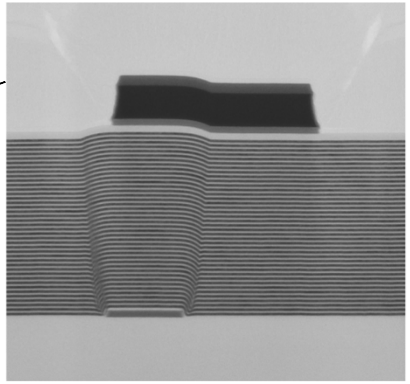


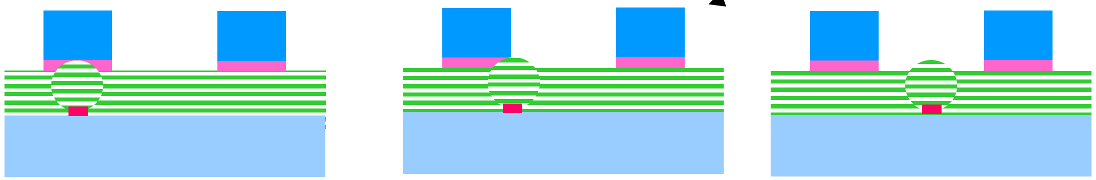

**Pattern edge profile of light intenisty**

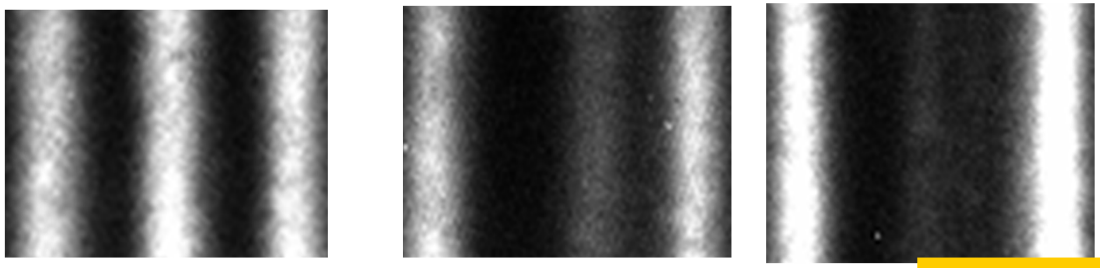
By 25% and 75% of maximum light intensity light for the absorber edge pattern, the resolution of 50nm is obtained.

# Printability of Mask Defect

Printability of phase defect under the absorber pattern





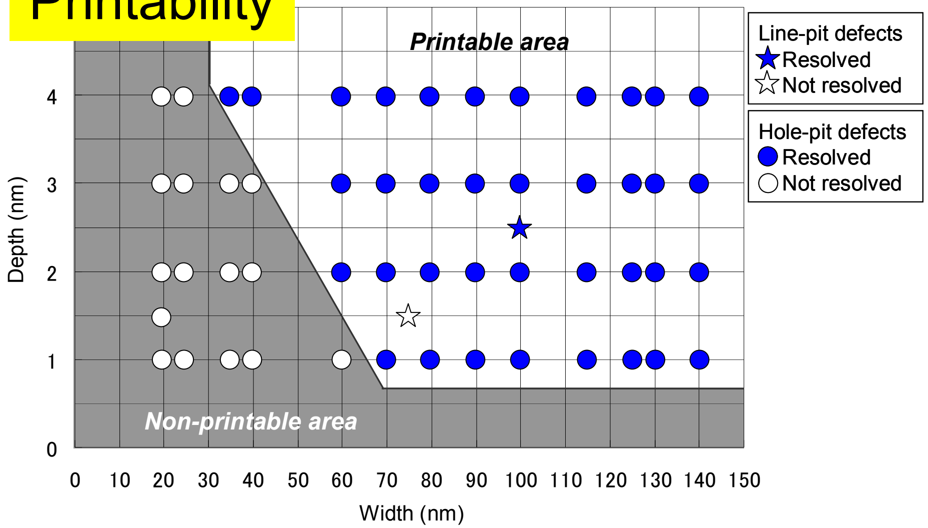


400 nm L/S, programmed defect height of 12 nm

Hp 400 nm

The printability depends on the position of the programmed defect.

Printability




Printability of point and line programmed defects

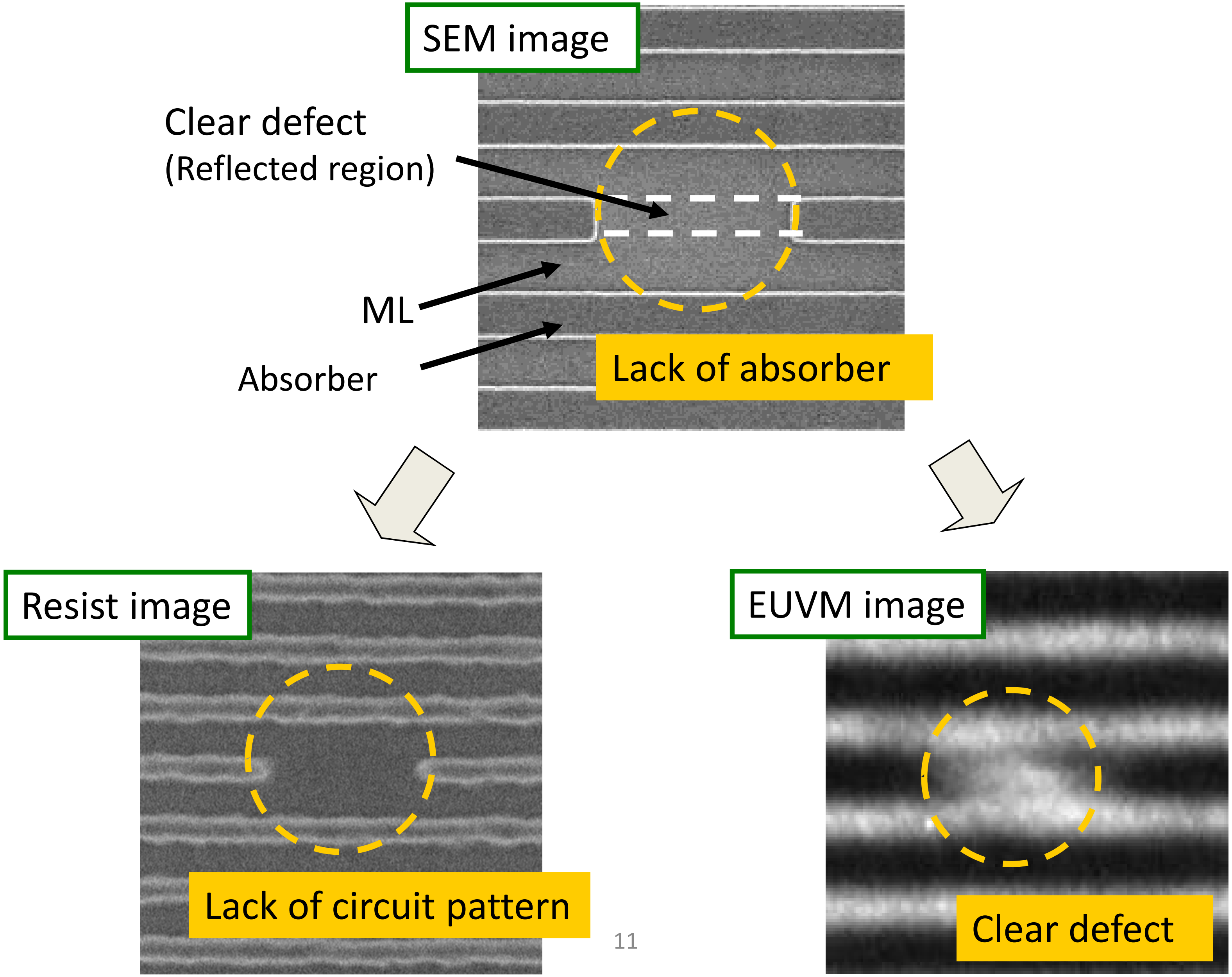
Controlled the width and height of the programmed defect.

Depth: 1～4 nm

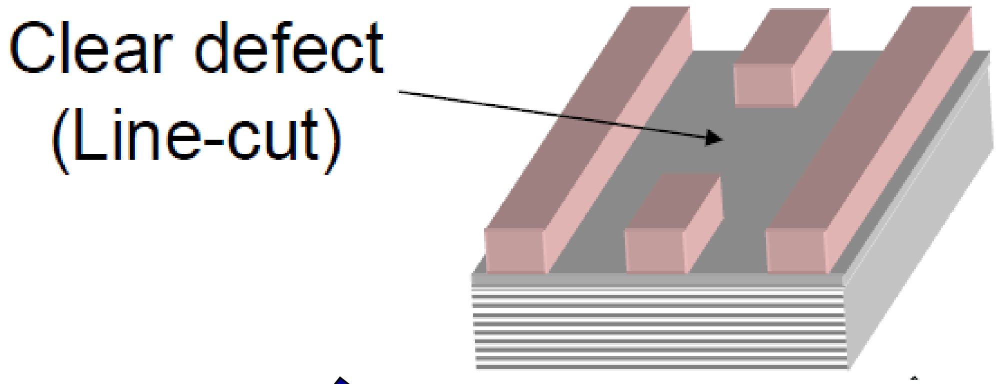
Width: 20～140 nm

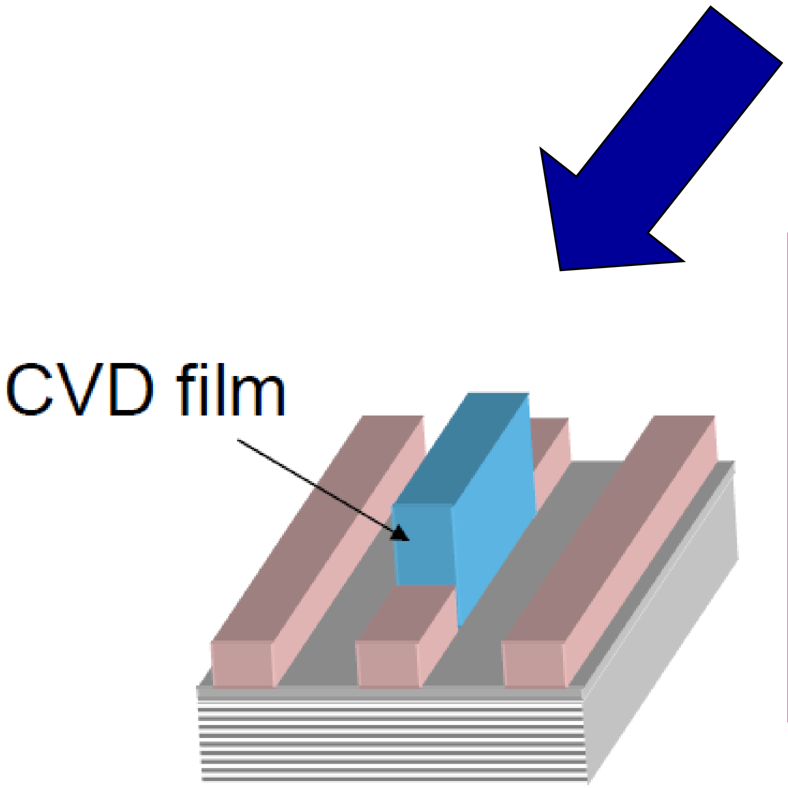
The printability criteria was clarified using EUVM.

# Repair of clear defect



# Conventional repairing method of clear defect by CVD

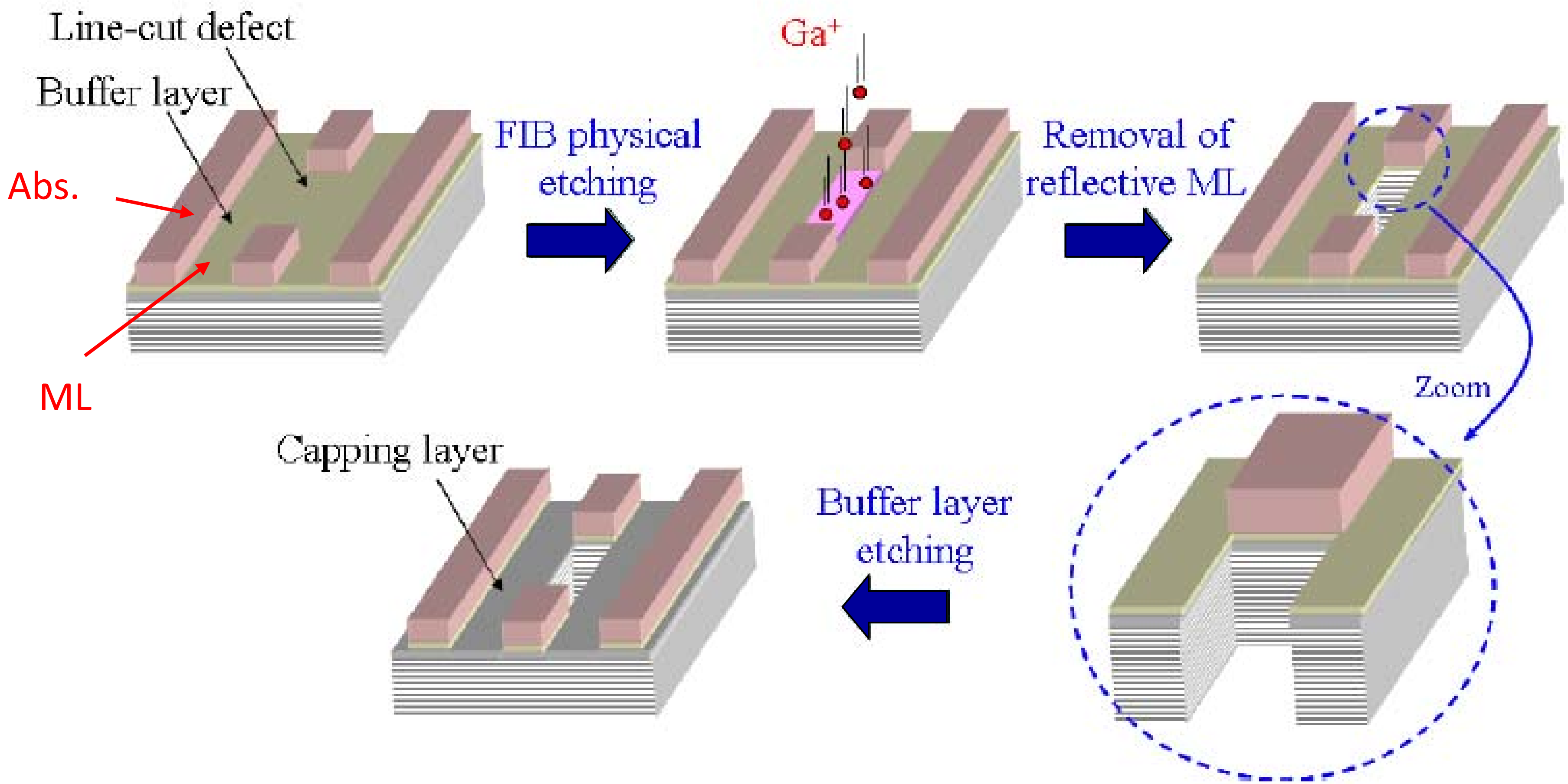



Demerrit：

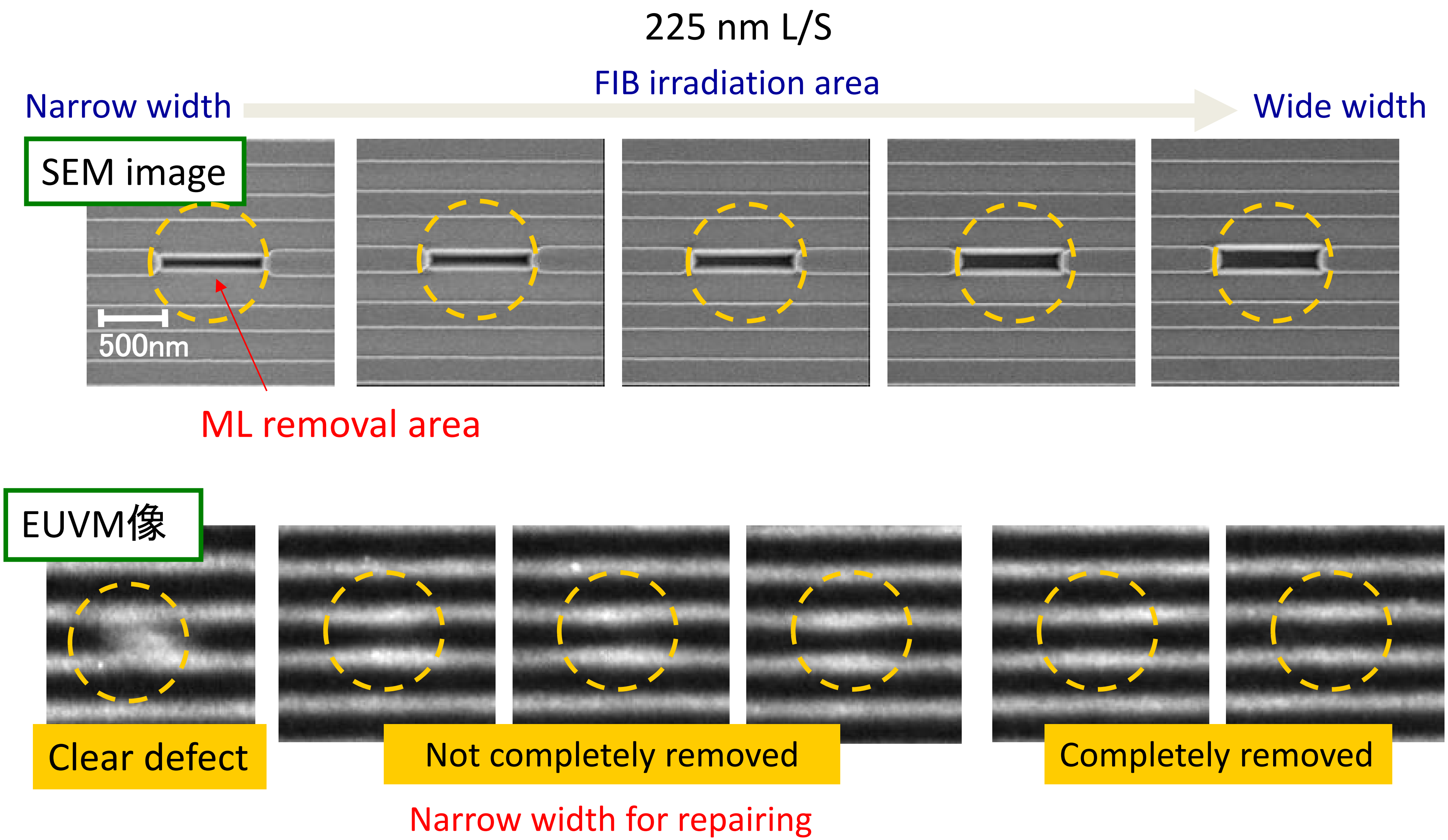
- CVD layer contains carbon.
  ➡ Thickness loss by cleaning.
- CVD layer has to be large height.
  ➡ Affected with shadowing effect

# Mask defect repair using FIB




By removing of the ML under the Clear defect by the Ga ion beam of FIB, the EUV light will not be reflected.

# Pattern inspection by EUVM for the repaired clear defect by FIB

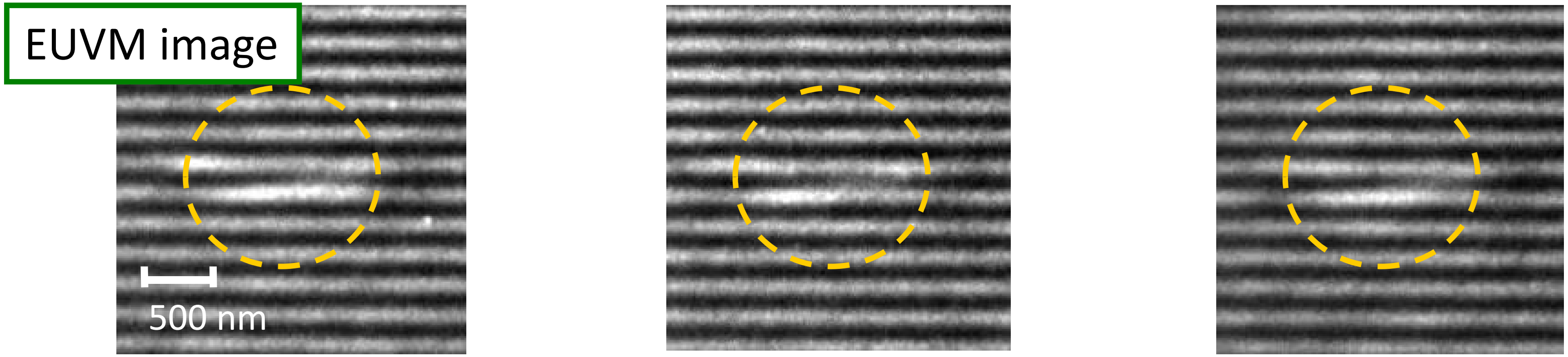


# Pattern inspection by EUVM for the repaired clear defect by FIB

128 nm L/S

FIB irradiation area

Narrow width → Wide width




The clear defect which was repaired by FIB was observed using EUVM.

# Conclusions

1) Printability criteria of the programmed defect width and height was obtained using EUVM mask defect inspection.
2) It is confirmed that the clear defect repairing by FIB is found to be usable using the EUVM observation.

# Acknowledgement

This research was supported by NEDO.

And the mask sample was prepared by Selete.

# EUV Microscope using a high-magnification objective with three multilayer mirrors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# Outline

1. **Motivation**

   Early studies and technical issues

2. **Experimental**

   Innovative optics utilizing high-magnification

3. **Highlight data**

   EUVL mask images with improved resolution

4. **Summary and future plans**

# 1. Motivation

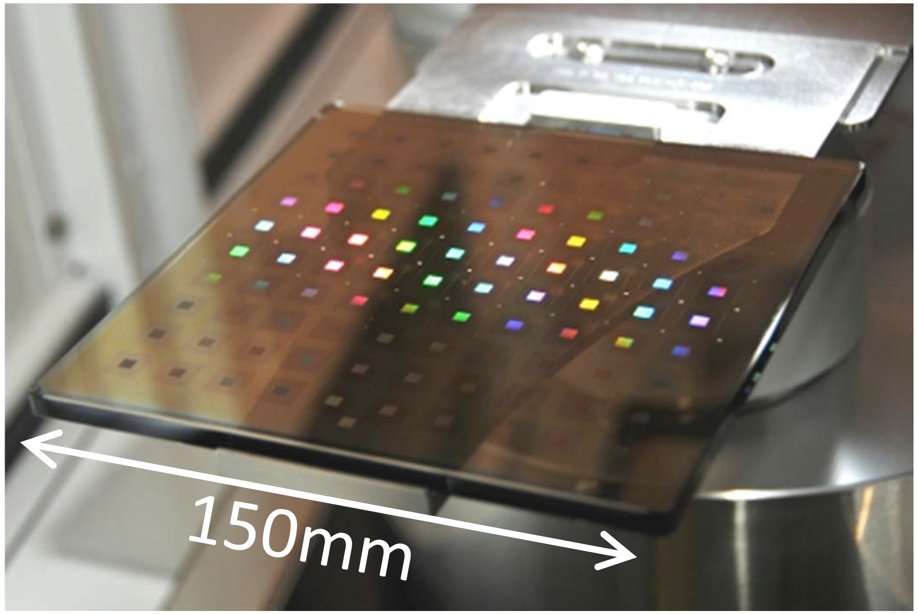
# Benefit of using high-magnification mirror as an objective

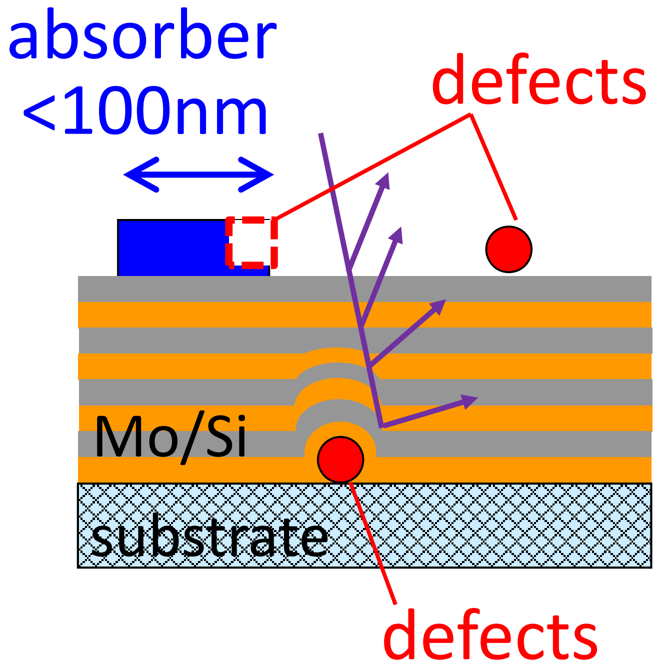
In the x-ray zooming tube, CsI thin film was utilized as the photoelectric conversion element.

However, the grain size of the CsI affected with the resolution of the EUVM imaging.

Thus the high-magnification-mirror objective is selected for the EUVM imaging.

# At-wavelength inspection of EUVL mask



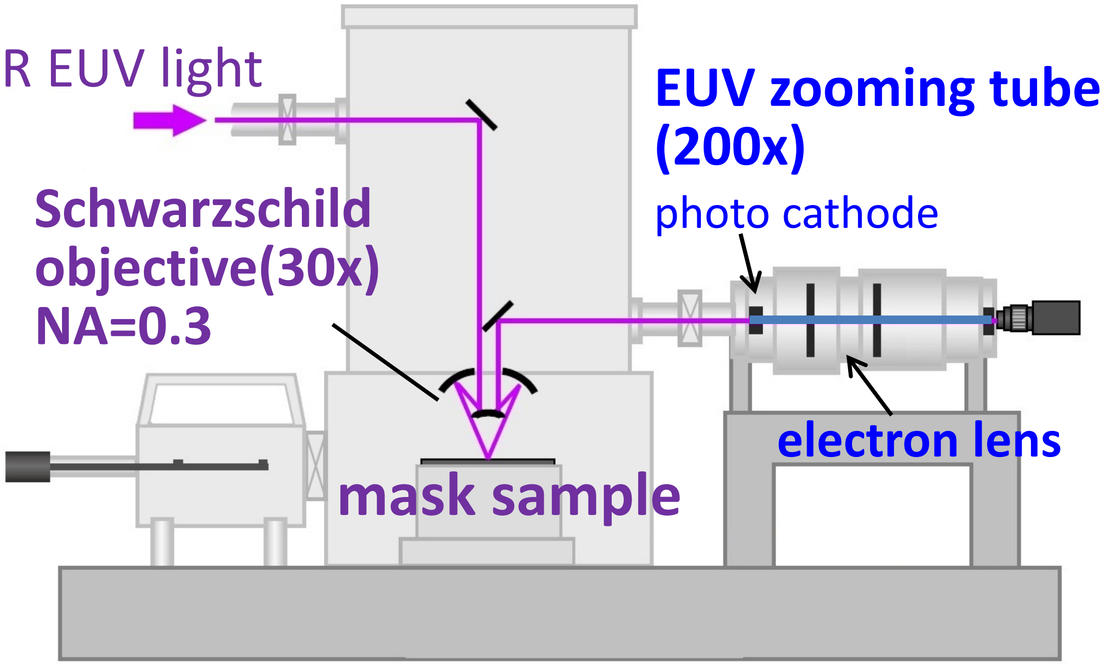

***Requirements for an inspection tool***

✓At-wavelength observation (λ=13.5nm)

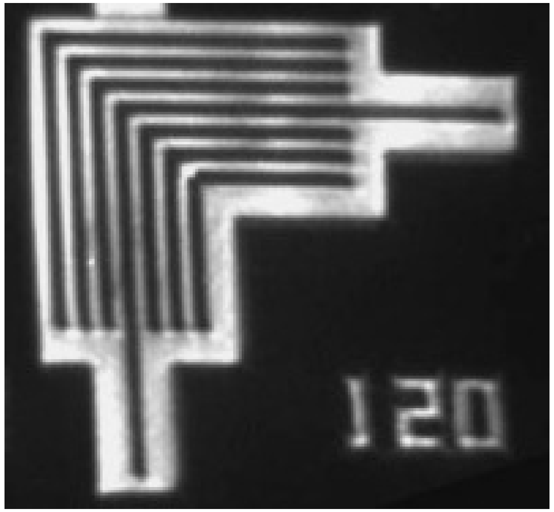
✓High spatial resolution (δ<40nm)

✓Wide field of view for a rapid whole mask inspection

# Early study: EUV Microscope on NewSUBARU




Line width 480nm
(120nm on wafer)




H. Kinoshita Jpn. J. Appl. Phys. **49**(2010)06GD07.

***EUV⇒electron***

✓Bright field image at λ=13.5 nm

✓Rayleigh's limit δ=30 nm

**Field of view Φ=20μm**

**Actual resolution δ>100 nm**

# Technical issues of the EUV Microscope

✓**Degraded resolution** resulting from
*aberrations of Schwarzschild objective.*

✓**Small field of view**
limited by an electron lens of the zooming tube.

**Aim of this work**

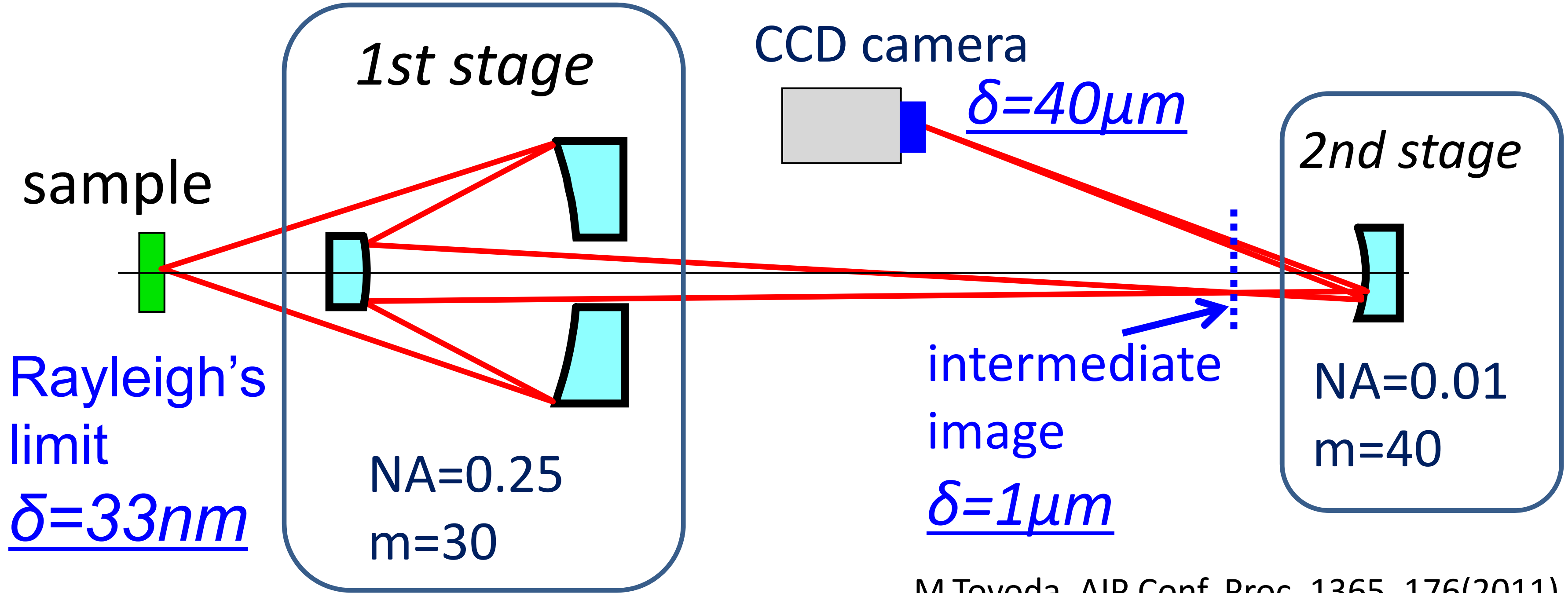
Innovative EUV imaging facility realizing both

✓**high spatial resolution for 22-nm node mask,**

✓**wider field of view for practical inspection time**.

# 2. Experimental

# Two-stage imaging system for high magnification




M.Toyoda, AIP Conf. Proc. 1365, 176(2011)

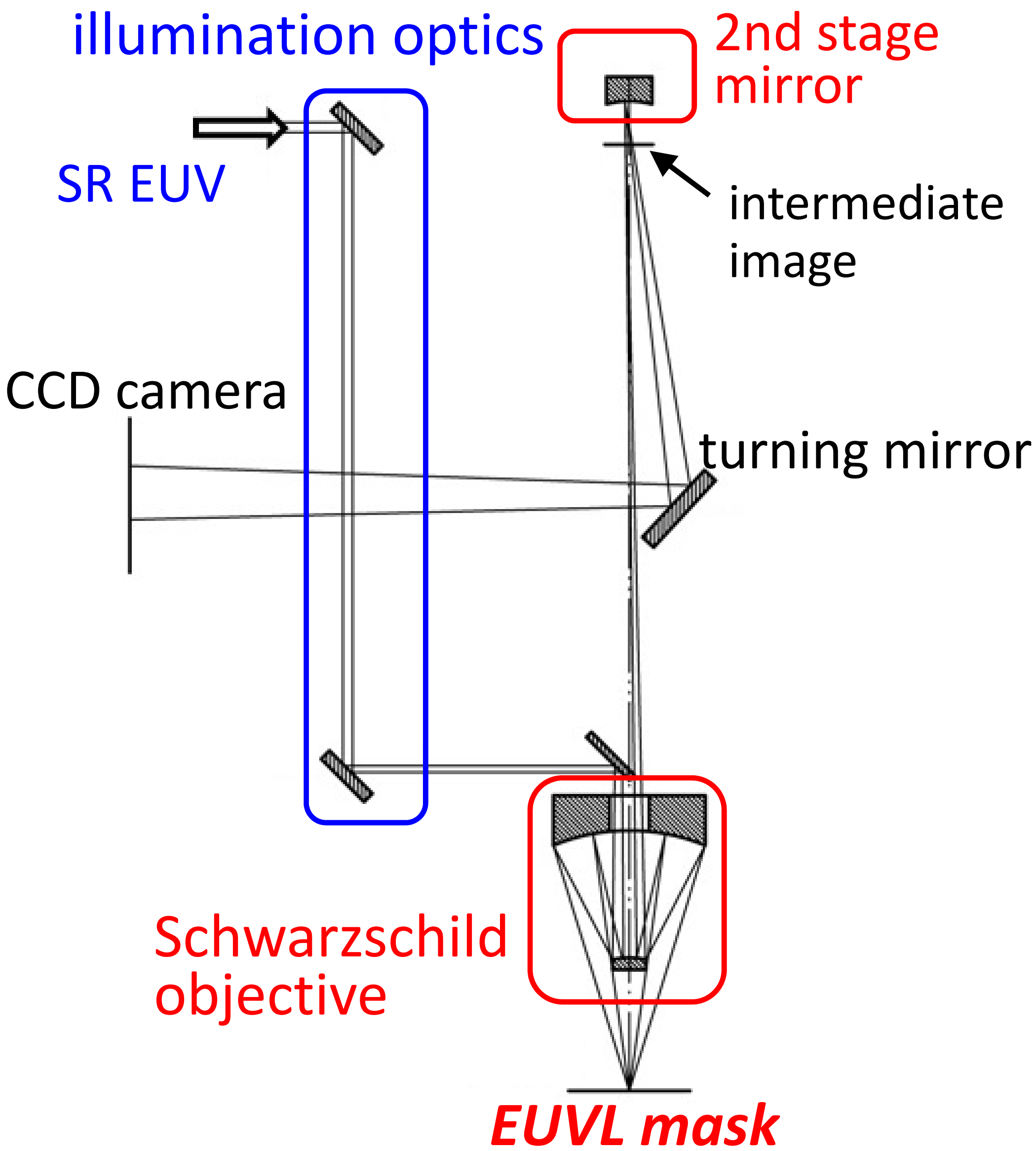
✓Higher magnification (m>1200)

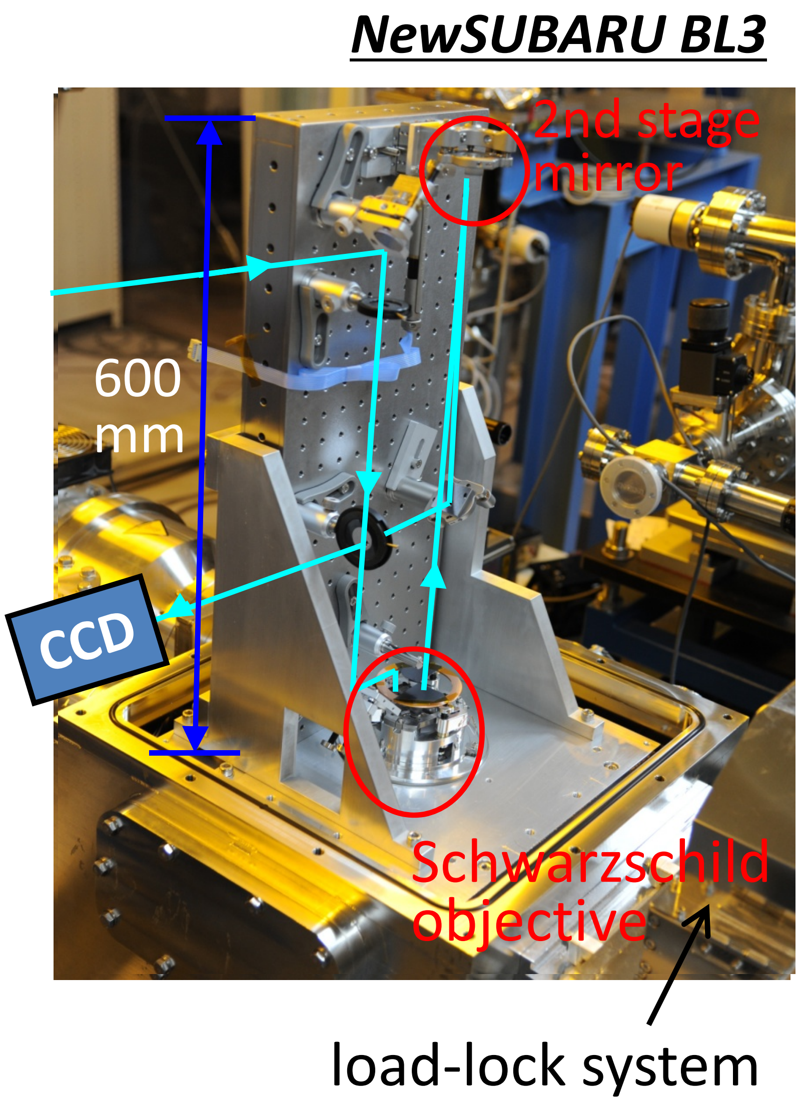
***⇒ 30nm resolution with EUV-CCD camera***

✓Good *correction of off-axis aberrations*

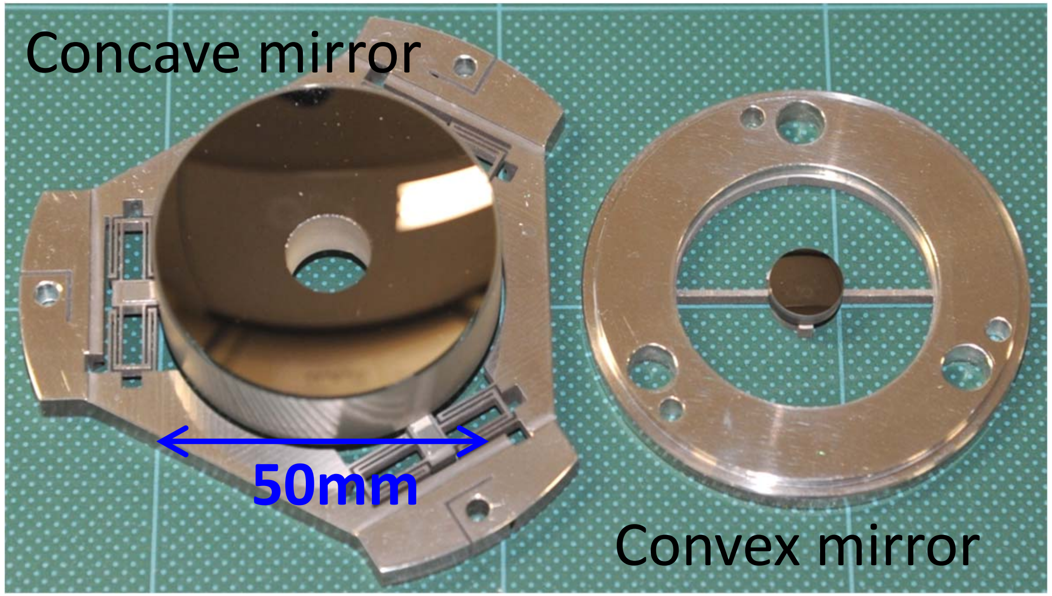
***⇒ Large field of view over Φ>160μm***

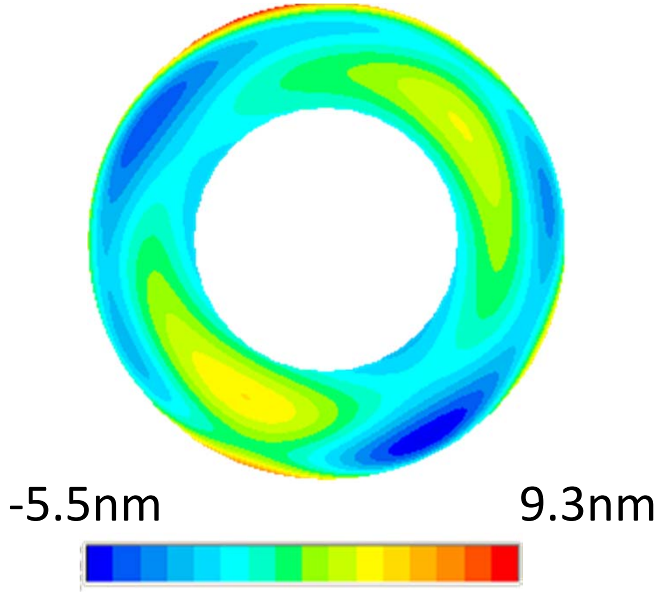
# Experimental setup of the novel facility



# Instrumentation of the imaging optics



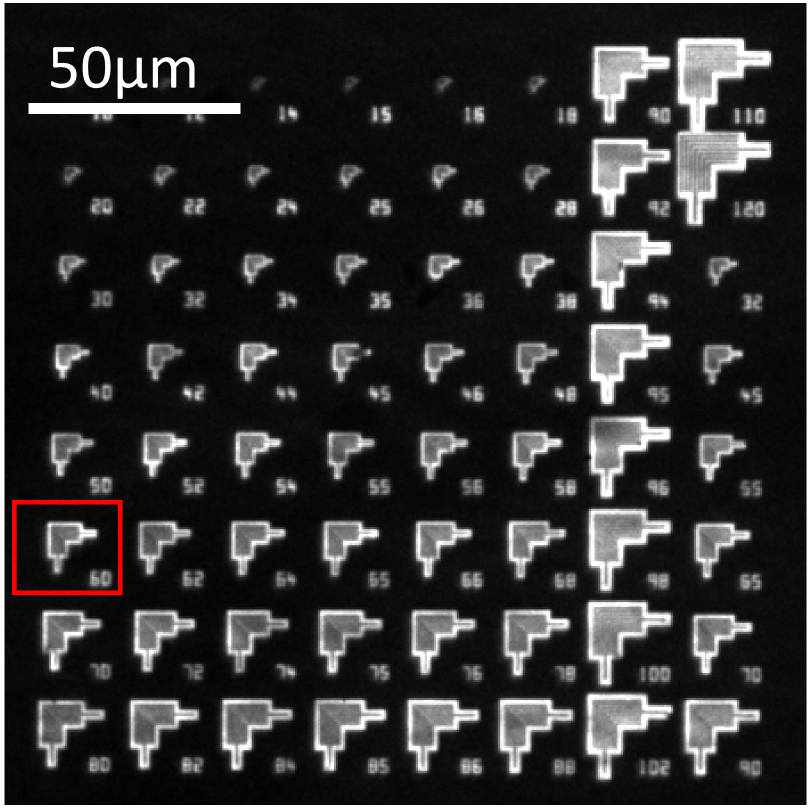




- ✓Substrates (5 sets) were polished in IMRAM.
- ✓Mo/Si multilayer was coated with IBS.
- ✓Mirrors were aligned using Zygo interferometer.

  ***⇒ Wavefront error W=2.2 nm rms. (on-axis)***

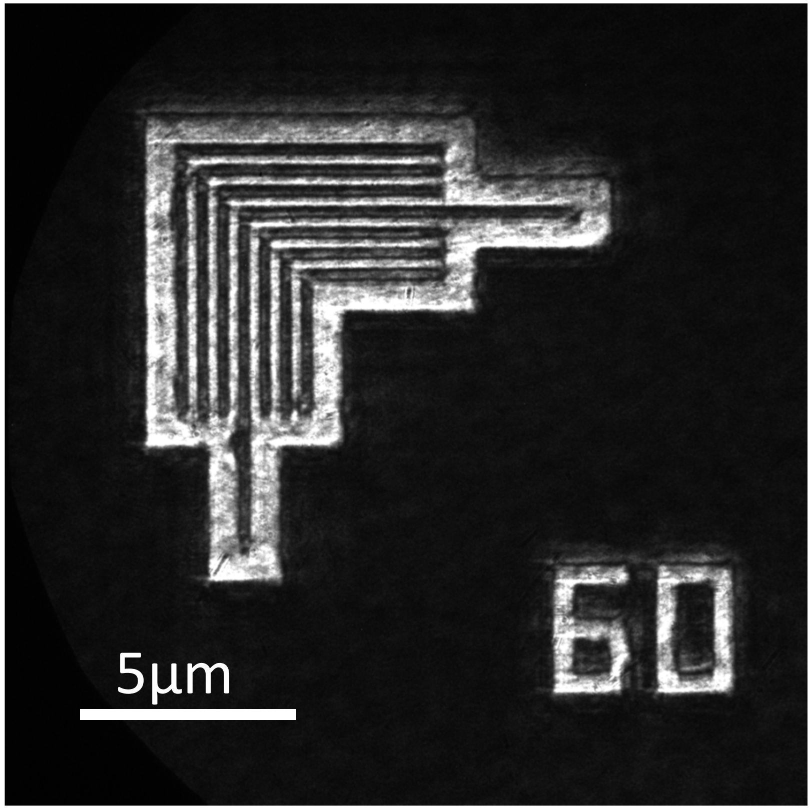
# <u>3. Highlight data</u>

# Confirmation of the magnification enhancement




***Intermediate image (m=30)***

Exp. time: 0.25 sec.




***Final image (m=1460)***

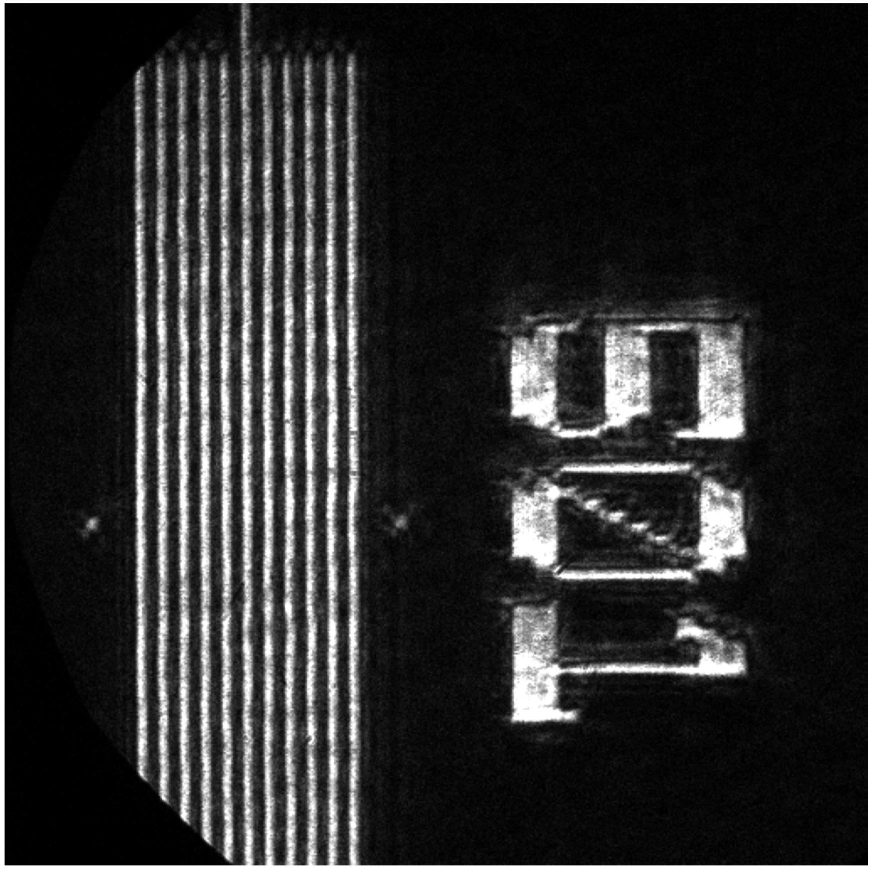
Line width: 240nm (60nm)

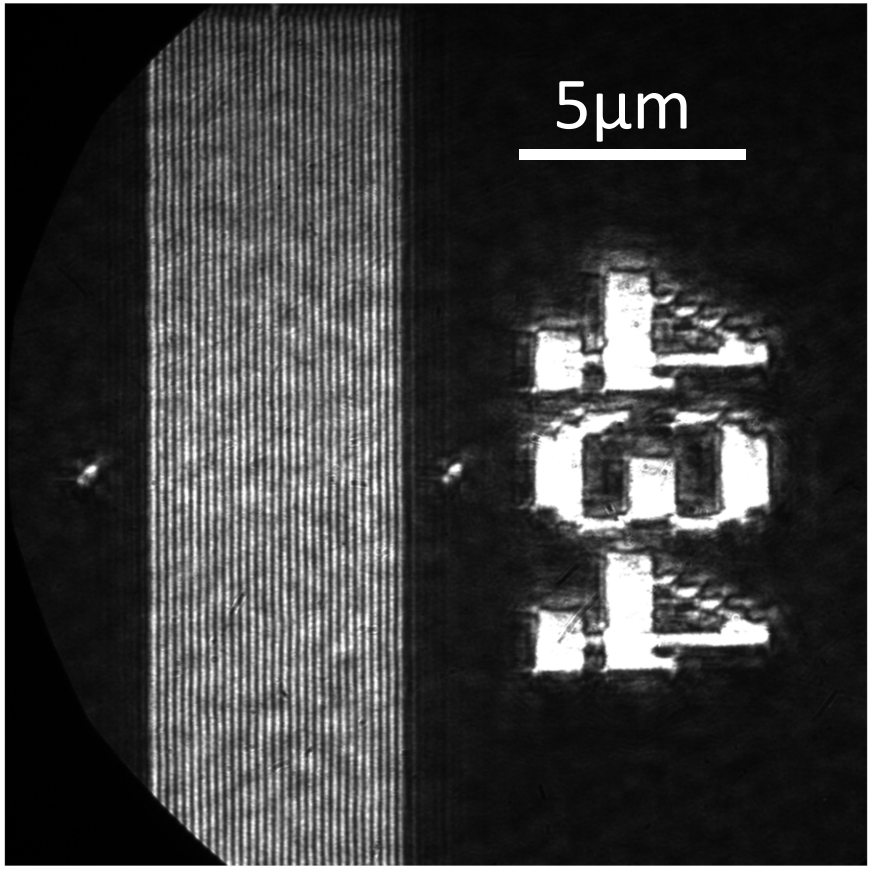
Exp. time: 36 sec.

EUV-CCD camera: pixel size 13.5µm, 2048 × 2048 pixels

# Resolution measurement with L/S patterns

## *High magnification images (m=1460)*

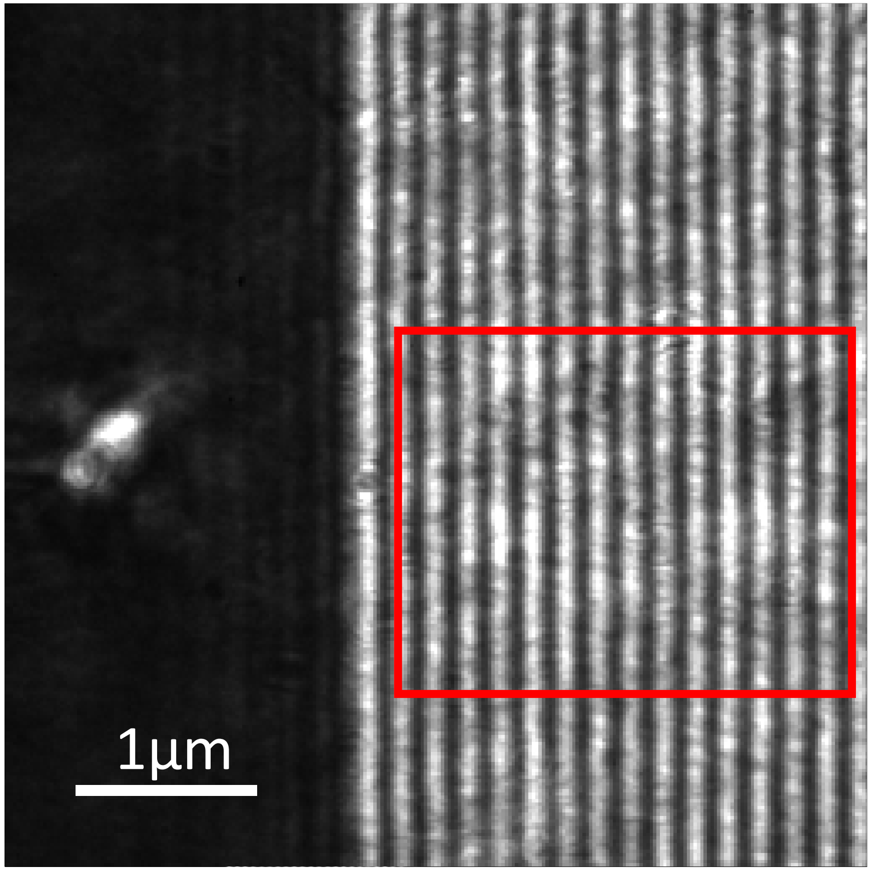


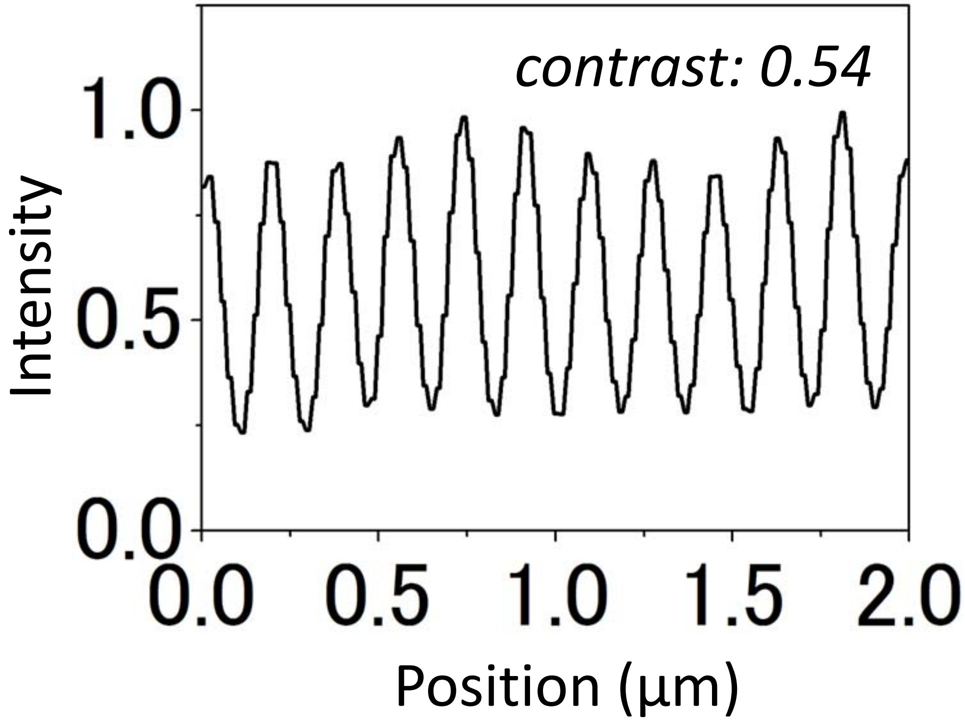



Line width: 225nm (56nm)
Exp. time: 10s

Line width: 88nm (22nm)
Exp. time:100s

# Resolution measurement with L/S patterns




✓88nm-width L/S pattern was clearly observed.

⇒The capability of inspecting 22nm-node masks.

# Conclusions

1) High-magnification of 1460x was achieved using three-mirror objective.
2) High-magnification enhancement was confirmed by the observation of the actinic EUV mask.
3) 88 nm mask pattern was observed using high-magnification objective in EUVM.

# Summaries

1) Printability criteria of the programmed defect was confirmed by EUVM.
2) The benefit of the clear defect repairing method using FIB was confirmed by EUVM.
3) 88 nm mask pattern was observed using high-magnification objective in EUVM.